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# Relationships between Organic Beef Production and Agro-Ecosystems in Mountain Areas: The Case of Catalan Pyrenees

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**Abstract:** This study analyzed the link between organic beef production and agroecosystems in mountain areas and the potential effects of land use change in eight farms of Catalan Pyrenees with a three step approach: (i) assessment of structural and management features; (ii) comparison of forage productivity and manure loads of 71 farmland parcels in relation with management intensity (natural meadows, seminatural meadows, temporary crops) and, for meadow parcels, with the farmers' willingness to convert them to temporary crops; (iii) life cycle assessment of the environmental impacts. Each farm managed around 150 ha of pastures and 23 ha of farmland (of which only 5 as temporary crops), and maintained a herd of around 130 livestock units. Forage productivity and manure loads of farmland were modest and extremely variable, and no productive advantages could be predicted from the conversion of meadows to temporary crops. Environmental impacts were mostly related to the on-farm stages, because of low-input management and very high feed self-sufficiency, and the diets used showed very low feed/food competition. These results indicate a balance between organic beef production and management of mountain agroecosystems, which is a key point for sustainability and should be a priority in European policies and strategies.

**Keywords:** livestock systems; mountain areas; grassland; organic production; life cycle assessment

## 1. Introduction

Grassland-based extensive livestock farming systems play a central role in managing and conserving High Natural Value Farmland (HNVF) areas in less productive regions, such as in European mountains [1–4]. These systems are highly multifunctional, because they indirectly or directly deliver a series of public, non-marketable benefits to the society, which can be described as non-provisioning ecosystem services (ES) [5,6]. The ES provided by mountain agroecosystems include, for example, the conservation of grassland habitats and the associated biodiversity, soil carbon storage and health [7,8], or the maintenance of cultural landscape and heritage and the provision of space for recreation and cultural experiences [9–11], protection from invasive species [12] and, particularly in Mediterranean regions, protection from forest fires [3,13,14]. Often, additionally, these extensive grassland-based systems are engaged in the production of typical high-quality products [15–17] such as organic beef. During the last decades, in the European mountain areas the traditional livestock systems based on extensive management of pastures and meadows have been strongly affected by two processes: intensification of farmland and herds management in suitable areas and abandonment in marginal areas [18,19]. As a result, mountain agroecosystems have been profoundly altered, with either a conversion to arable crops and intensification of farmland management or reforestation of abandoned grasslands [14,20], with the resulting loss of the associated ES [10,21,22], which, although non-marketable, are highly valued by society [11,23] such as the maintenance of pasture and meadows guaranteed by animals' grazing. The main factors determining abandonment are family constraints, topographic and climatic conditions, economic and social elements [24,25] since, for example, farming profitability is lower and not sufficient for the families' sustenance. In order to overcome these constraints, the European Common Agricultural Policy (CAP) recognizes the important multifunctional role of extensive livestock systems in delivering positive externalities [26] and provides financial support to maintain pastures and meadows through regional Rural Development Programs, as for example with Agro-Environmental and Climate measure 10 (M10) that, in the Catalonia region of Spain, provides financial incentives to management of pasture and meadows [27].

With the recent rise of public concern on climate change and, more in general, on the environmental impacts of anthropic activities, the contribution of livestock farming has been debated and the need for mitigation measures clearly outlined [28]. In this perspective, grassland-based livestock systems have been reported as notable contributors to the total anthropogenic greenhouse (GHGs) or acidifying gases emission, especially if beef systems [29]. Assessments based on the life cycle assessment (LCA) methodology [30] reported higher impacts per unit of product for roughage-based with respect to concentrate-based beef systems, because of lower growth rates, longer finishing periods and greater enteric methane emissions [31,32]. In the recent years, an increasing number of grassland-based beef farms have been converted to the organic production system, since characteristics such as the use of meadows and pastures and the low off-farm feedstuffs purchase share favor the accountability to organic label regulations [33,34], and the beef may be marketed at higher prices [35]. However, organic beef production has generally a lower productivity than conventional production, and consequently, greater impacts per unit of product [29]. Improvements in feeding strategies with use of high-energy feeds would mitigate emissions [36], but would also require an intensification of farmland management that could impact on the various ecosystem services that are linked to extensively managed grasslands [6]. Improving knowledge on this trade-off is therefore important for addressing the sustainability of organic beef farming in mountain areas [37].

In the Catalan Pyrenees, the number of farms engaged in organic beef production has been steadily increasing during the last years. We found a gap in literature regarding these livestock systems and their relationships with the use of local resources and mountain agroecosystems. This research aims to give new insights for farmers and policy makers, useful to define strategies and policies for the sustainable development of organic grassland-based beef systems.

With this general goal, this study examined the link between mountain agroecosystems and the environmental impacts of the organic beef systems in the Catalan Pyrenees. We surveyed a representative sample of farms with three specific aims. First, we described the land and herd management features, to assess the type of agroecosystems used and the farming management intensity. Second, with the of aim of determining whether an intensification of land management would predictably lead to an increase in productivity, we compared forage production and manure loads among meadows and temporary crops parcels, and, for meadows, in relation with the willingness of farmers to convert them to temporary crops. Third, we assessed with an LCA approach the environmental impacts and the diet energy efficiency of the farms sampled, to analyze the contribution given by each emissions source and the competition between feed and food (potential human-edible fraction of animals' diet) related to this organic beef production.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted in the Alta Ribagorça and Cerdanya comarcas (counties) in the Catalan Pyrenees (Province of Lleida, North of Spain) (Figure 1). Alta Ribagorça has a surface of 427 km$^2$, corresponding to 1.3% of the total surface of Catalonia, and an altitude between 800 and 3000 m a.s.l. Cerdanya is divided into High Cerdanya (the northern part, in France) and Low Cerdanya (the southern part, in Spain) with a total surface of 1806 km$^2$ (547 km$^2$ in Spain, corresponding to 1.7% of the total surface of Catalonia). The climate is influenced by the transition between the Atlantic climate, with humid influences in the western Pyrenean regions, and the continental Mediterranean climate of the eastern Pyrenees [38], and is classified as temperate oceanic (Cfb, according to the Köppen-Geiger climate classification). In Alta Ribagorça the average annual temperature is of 10.1 °C (maximum in June and July and minimum in January) and the average precipitation of 639 mm, in Cerdanya the average annual temperature is of 9.8 °C (maximum in July and minimum in February) and the average precipitation of 619 mm.

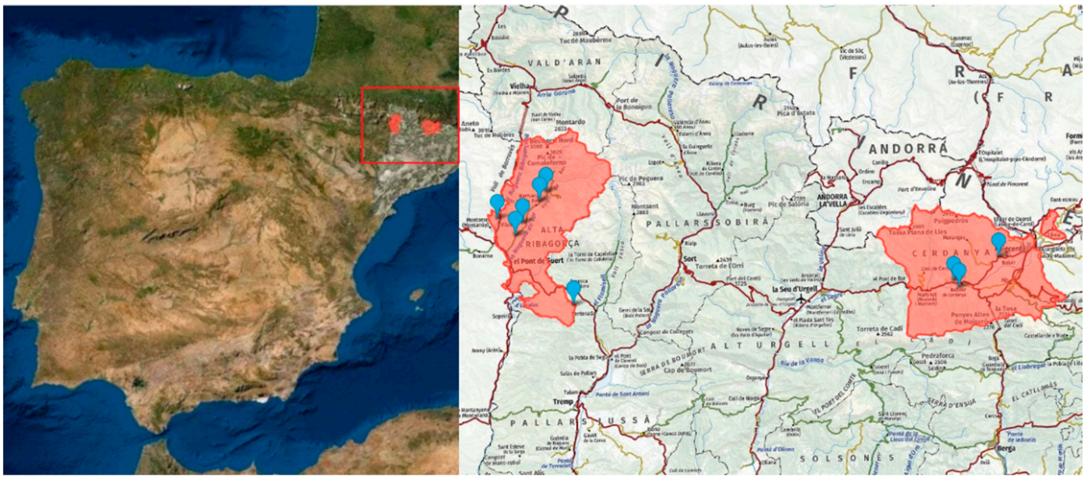


**Figure 1.** Study area. The red polygons on the right panel indicate the two comarcas: Alta Ribagorça on the left and Cerdanya on the right. Blue dots indicate the farms' locations. Source: Institut Cartogràfic i Geològic de Catalunya (ICGC). https://www.instamaps.cat/visor.html?businessid=155012c20c330e3f60e6edd0251ab210&3D=false.

In Catalonia, 2048 km$^2$ of Utilized Agricultural Area (UAA) are managed according to practices complying with the organic farming regulations; 1093 km$^2$ are located in the province of Lleida, predominantly (81.8%) represented by pasture and meadows [27] (see Figure 2a,b). The livestock farms engaged in organic beef production are 971, 260 of which are located in the province of Lleida with a total production of 407.7 tons of carcass weight [39].

(**a**) (**b**)

**Figure 2.** On (**a**), hay mowed for hay; on (**b**) cows at highland pastures.

In both Alta Rigaborca and Cerdanya, land cover is mostly "forest" (95% and 88.1% of total surface, respectively) which includes woods, scrubland, meadows, pastures and other grasslands, wetlands (Table 1; meadows, pastures and other grasslands are merged into forest because there is no clear distinction between grazed forest and grasslands). More specifically, 26% of the study area is covered by mid-elevation or highland pastures. The density of cattle farms is close to 1/km$^2$ of UAA and the cattle stocking rate is 0.2–0.3 LU/ha of UAA, in both comarcas [40].

**Table 1.** Total surface and land cover, utilized agricultural area (UAA), number and density of cattle farms and livestock units (LU) in Alta Ribagorça (AR) and Cerdanya (CE). Source: Institut d'Estadística de Catalunya (IDESCAT).

| Variable | AR | CE |
|---|---|---|
| Total surface, km$^2$ | 426.8 | 546.7 |
| Forest [1], km$^2$ | 403.6 | 481.6 |
| Land with no vegetation [2], km$^2$ | 11.6 | 10.7 |
| Cropland, km$^2$ | 7.9 | 33.7 |
| Urban land, km$^2$ | 3.9 | 21.0 |
| UAA, km$^2$ | 114.2 | 286.0 |
| Farms [3], N | 77 | 299 |
| Farms/km$^2$ UAA | 0.7 | 1.0 |
| LU, N | 2644 | 9884 |
| LU/farm | 34.3 | 33.1 |
| LU/km$^2$ UAA | 23.2 | 34.6 |

[1] Forest includes woods, scrubland, meadows, other grassland, pasture and wetlands. [2] Land with no vegetation includes bare soils, rocky land and glacier. [3] The data refer to dairy milk and beef farms.

Part of Alta Ribagorça is occupied by the Parc Nacional d'Aigüestortes i St. Maurici, a protected area located between the Alta Ribagorça, Pallars Jussà and Pallars Sobirà comarcas (400 km$^2$), whereas in Cerdanya the Cadí-Moixeró Natural Park is located between the Berguedà, Alt Urgell and Cerdanya *comarcas* (410 km$^2$).

In the province of Lleida, in particular in the Catalan Pyrenees, organic beef production is linked to the management of organic pastures and meadows. According to the Rural Development Program of Catalonia, the number of organic farms is growing and becoming very important in the local livestock production [27]. In the province of Lleida, the number of farms engaged in organic beef production has increased from 4 in 2000 to 260 in 2019. Specifically, in Alta Ribagorça and Cerdanya, organic livestock farms account for 47% and 12% of total livestock farms, respectively [41].

### *2.2. Data Collection*

The survey took place in 2018, involving eight farms specialized in organic beef production, which had already established a collaboration with the University of Lleida. The farms were representative of the study area's production context, and all the farmers engaged in this study were employed part-time, because livestock farming alone does not supply for the family sustenance. Data collection and data editing are illustrated in Figure 3.

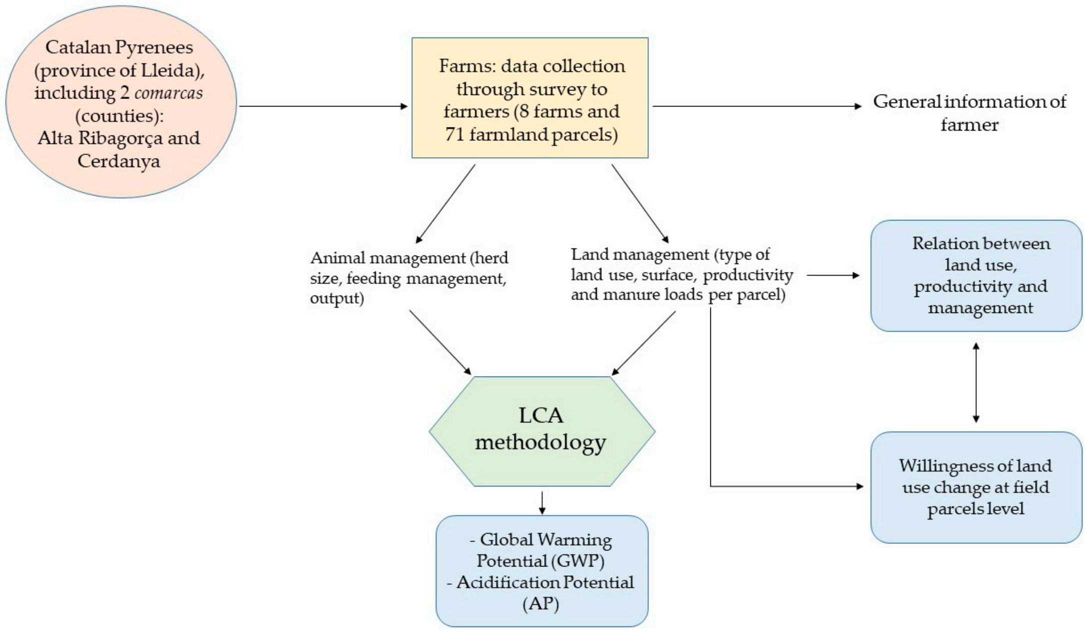


**Figure 3.** Flow chart illustrating the steps of the methodology used, including the data collection and the study area.

The survey was divided into three parts, and collected a large set of data for each farm (see Table S1 for a detailed description of variables collected). The first part described the general features of the farms and specified data on herd size (number of suckler cows and replacement heifers), breed, reproduction management (calving seasonality), calf management and the relative fattening period. In addition, the diet composition during the in-house period (amount and type of forages and concentrates) was collected for both fattening calves and cows. The second part described the utilized land and its features. Land uses comprised natural meadows, seminatural meadows, and temporary crops, which we will define hereafter as "farmland," in addition to highland and transition pastures. The distinction between natural and seminatural meadows is based on the past management (plowing and reseeding, see Table S1), while temporary crops include forage and cereal crops (Alfalfa, sorghum, etc.) Highland pastures are summer pasture located at high altitudes, above the treeline (2200–2400 m a.s.l.), which are grazed during summer (June–September), whereas transition pastures are located at mid elevations and are grazed during the spring and autumn transhumance to and from the highland pastures. Both types of pastures do not pertain to a single farm, but are municipal properties and collectively managed. Most of the natural/seminatural meadows and temporary crops are instead owned by the farms, and the few others are rented. Meadows are mowed to produce hay but may also be grazed at the beginning of spring and end of summer, before and after the use of transition and highland pastures.

Each parcel of farmland was geo-referenced (Google Earth and Digital Land Parcel Identification System, LPIS), and its average slope was calculated considering the slope of each fenced sub-parcel weighted by its surface. Information on productivity (kg DM/ha), manure inputs (kg/ha) and irrigation management (yes/no) was also recorded (Table S1). Besides, for each parcel, the willingness of farmers to change or not land use was recorded, with land management shift and the reasons for the desired change.

### 2.3. Environmental Impacts

The environmental impacts were computed using the LCA methodology [30]. This methodology aims to evaluate the environmental burden associated with one unit of a product, considering the different phases of its cycle and including both the direct impacts related to its production, use and disposal and the indirect impacts embodied in the inputs in its production [30,42]. The ISO standard prescribes four different phases: goal and scope definition (setting on the model characteristics), life cycle inventory (data collection and emission calculation), life cycle impact assessment (computation of each impact category) and interpretation of the results.

#### 2.3.1. Goal and Scope Definition

To compute the environmental impact, a cradle-to-farm gate model was adopted, with the farm as reference unit. Since the farm output consists of animals sold to slaughterhouse (fattened male and female calves, culled suckler cows), 1 kg of Body Weight (BW) sold was chosen as the functional unit to which the impact is referred. The impact categories were global warming potential (GWP, kg $CO_2$-eq), as livestock systems are notable contributors to anthropogenic GHG emissions, and acidification potential (AP, g $SO_2$-eq) as acidifying N-related compounds released by livestock systems could have negative effects on a local scale [43]. The system boundaries considered the management of animals, manure, farm-land for on-farm feedstuffs production (in house and pasture period) and the purchase of off-farm feedstuffs included in the animal diets.

#### 2.3.2. Life Cycle Inventory and Life Cycle Impact Assessment

Emissions computation was performed for each animal category (suckler cows, weaning calves, male and female calves for fattening, female calves for replacement, heifers at the first year and heifers at the second year). Information was collected for each animal category and concerned the number of animals, age, in-house and grazing periods, the initial (BWI) and final (BWF) body weight and diet (Supplementary Tables S1 and S2). The average daily gain (ADG, kg/day) was calculated as (BWF-BWI)/days of presence.

Feed intake (kg DM) was computed for each animal category, considering the relative in-house and grazing periods during the year. For each animal category, feed intake during the in-house period was computed as the ratio between net energy (NE) requirements [44,45] and the NE content of the diet (MJ/kg DM, values derived from INRA 2007) [46]. The consumption of each feedstuff was computed on the basis of its relative percentage of inclusion in the ration. The total farm consumption of each diet was computed as the sum of the daily intake of each feed per animal category multiplied for the in-house period days and for the number of animals. Feed intake during the grazing period was computed with the same procedure used for the in-house period (NE value for grass at pasture derived from INRA (2019) [47].

Nitrogen (N) input–output balance was calculated considering each animal category and following Katelaars and Van der Meer (1999) [48] (Supplementary Table S3). Specifically, the N intake was calculated as the feed intake (kg DM/d) × presence days (in-house/grazing) × crude protein diet content/6.25. The N retention was computed considering the retention due to BW gain (retention factors: 0.025 kg N/kg BW for sucker cows and heifers, 0.028 kg N/kg BW for weaned calves for fattening or replacement, 0.032 for pre-weaning calves) [49], retention in the milk (mean production: 6.5 kg/cow/day [50]) and pregnancy. N excretion was calculated as the difference between N intake and N retention. The data collected regarded also the age and the final body weight sold at the time of sale, the number of the days in-house and on pasture and the relative diet, in particular the quantity of N.

#### 2.3.3. Emissions Computation and Life Cycle Impact Assessment

Carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) contribute to GWP. Emissions derived from manure storage at the farm ($CH_4$ and $N_2O$) and agricultural soils management ($N_2O$ from manure and fertilizers spreading) were computed with the equations of the International Panel of Climate Change [45] (Supplementary Table S3), applying the approach derived from Berton et al. 2017 [51]. Enteric $CH_4$ was calculated according to the IPCC procedure, using enteric methane yields based on the diet composition according to Ramin and Huhtanen, (2013) [52]. The acidification potential was computed considering the emissions of ammonia ($NH_3$), sulphur dioxide ($SO_2$). Nitrogen volatilization from manure storage and crop fertilization was calculated according to the IPCC equations [45]. The emissions related to GWP and AP due to purchased feedstuffs were derived from the Ecoinvent database [53]. Conversion of each pollutant compound into the relative unit of every impact category, relative to GWP and AP, was derived from Myhre et al. (2013) [54] for GWP (the common unit is kg $CO_2$-eq converted as: $CO_2$ = 1; $CH_4$ = 28 and $N_2O$ = 265) and from Guinée et al. (2002) [55] for AP (the common unit is $SO_2$-eq:1 converted as: $SO_2$ = 1; $NH_3$ = 1.88).

#### 2.3.4. Gross Energy Conversion Ratio

The ECR, defined as gross energy conversion ratio (MJ feed/MJ beef) and the HeECR, defined as potentially human edible–gross energy conversion ratio (MJ feed/MJ beef) were estimated according to Berton et al. (2017) [51] (Supplementary Table S3) considering each animal's categories. The computation of the potential human-edible fraction of animals' diets was based on Ertl et al. (2015) [56] The carcass yield, the boneless fraction of the carcass and the value of gross energy/kg of edible beef were the same as used by Berton et al. (2017) [51].

### *2.4. Statistical Analysis*

We log-transformed productivity and manure load values of the 71 parcels to obtain a normal distribution, and analyzed them using the nlme package [57] in R 3.6.1 [58], with a linear mixed model including the effects of land use (natural meadow, seminatural meadow, and temporary crop), irrigation (yes, no) and their interaction, plus the willingness of the farmer to shift land use (yes/no), and the random effect of the farm. We included the willingness to shift land use as a factor because we wanted to verify whether the assertion of farmers that they wanted to shift land use in the most productive meadow parcels was based on a real difference in productivity.

## 3. Results

### *3.1. Farms Structural and Managment Features*

Table 2 reports the descriptive statistic of the farmers' age and general land and herd management features. Farmers' average age was 40 ± 17 years; the variability was great, with a range from 26 to 73. Grasslands were largely predominant in the agroecosystems managed. Highland pastures were used by most of the farmers (7 out of 8) and showed the largest average surface (147 ± 116 ha) while transition pastures were smaller (17.0 ± 21 ha) and used only by five farmers. Farmland covered on average 22.6 ha, mainly composed of natural and seminatural meadows (15.4 ± 8.3 ha and 2.8 ± 2.7 ha, respectively), with temporary crops being 4.9 ± 3.4 ha. All these land uses showed a very wide variability between farms, with coefficients of variation (CV) close to, or exceeding, 100%, with the only partial exception of natural meadows (CV = 65%). Natural meadows were also the only land use present in all the farms.

The average herd size was 133 ± 52 LU, which corresponds to an average stocking rate (including collective pastures) of 0.7 LU/ha. The cow replacement rate was 14.8% per year, indicating a long lifespan. Male and female calves were sold at similar BW sold (479 ± 93 and 469 ± 97 kg/head/year, respectively) and showed similar average daily gains (ADG) (1.10 ± 0.08 kg/day and 1.07 ± 0.07 kg/day, respectively). The computed average daily feed intake of cows was 9.8 ± 0.2 kg DM, almost all deriving from forages, with an important contribution of pastures (39.7% of DM intake from grass at pasture). For pre-weaning calves the average daily feed intake was 3.4 ± 0.1 (32.4% derived from pasture) whereas for calves replacement females the average daily feed was 5.7 ± 0.5 (32.4% derived from pasture). The total yearly feed intake per LU averaged 3764 ± 362 kg DM, with only 8% (306 kg DM) deriving from concentrates, and an average crude protein content of 12% DM. For the detailed diet of cows and fattening calves see Table S3.

**Table 2.** Descriptive statistics of farmers' age, surface and type of managed land, herd size, management features and feeding.

| Variable | Unit | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Age of farmer | N | 40 | 17 | 26 | 73 |
| Managed land [1] | | | | | |
| Highland pastures | ha | 147.8 | 115.5 | 0.0 | 386.0 |
| Transition pastures | ha | 17.0 | 21.2 | 0.0 | 51.4 |
| Farmland | ha | 22.6 | 6.5 | 11.2 | 30.7 |
| Natural meadows | ha | 15.4 | 8.3 | 5.5 | 25.1 |
| Seminatural meadows | ha | 2.8 | 2.7 | 0.0 | 6.7 |
| Temporary crops | ha | 4.9 | 3.4 | 0.0 | 9.9 |
| Herd size and management | | | | | |
| Cows | N | 80 | 32 | 51 | 130 |
| Bulls | N | 3 | 1.2 | 1 | 5 |
| LU [2] | N | 133 | 52 | 77 | 215 |
| Replacement rate | % | 14.8 | 4.6 | 9 | 22 |
| Season of calving | | S, A [3] | | | |
| Calves/cow/year | N/year | 0.9 | 0.0 | 0.8 | 0.9 |
| Calves sold/cow/year | N/year | 0.7 | 0.1 | 0.6 | 0.8 |
| Calves performance | | | | | |
| Age at sale (male and female) | months | 13.1 | 2.0 | 12 | 18 |
| BW [4] sold/year (male) | kg BW | 479 | 93 | 400 | 700 |
| BW sold/year (female) | kg BW | 470 | 97 | 400 | 700 |
| ADG [5] male | kg/day | 1.10 | 0.08 | 0.99 | 1.21 |
| ADG female | kg/day | 1.07 | 0.07 | 0.99 | 1.21 |
| Feeding | | | | | |
| Feed intake, cows | kg DM [6]/cow/day | 9.8 | 0.2 | 9.5 | 10.1 |
| Grass at pasture | % feed intake | 39.7 | 14.9 | 27.7 | 70.5 |
| Hay and other forage | % feed intake | 58.8 | 17.2 | 22.2 | 72.3 |
| Corn silage | % feed intake | 0.2 | 0.6 | 0.0 | 1.7 |
| Concentrates | % feed intake | 1.3 | 2.6 | 0.0 | 7.2 |
| Feed intake, calves pre-weaning (0–6 months) | kg DM[6]/calve/day | 3.4 | 0.1 | 3.3 | 3.5 |
| Grass at pasture | % feed intake | 32.4 | 31.1 | 0.0 | 75.5 |
| Hay and other forage | % feed intake | 41.4 | 31.5 | 0.0 | 75.9 |
| Concentrates | % feed intake | 1.5 | 3.9 | 0.0 | 11.2 |
| Milk | % feed intake | 24.7 | 0.6 | 24.0 | 25.7 |
| Feed intake, calves female for replacement [7] (6–12 months) | kg DM/calve/day | 5.7 | 0.5 | 4.9 | 6.4 |
| Grass at pasture | % feed intake | 32.4 | 40.0 | 0.0 | 100.0 |
| Hay and other forage | % feed intake | 67.6 | 40.0 | 0.0 | 100.0 |
| Feed intake, LU | kg DM/LU/year | 3764 | 362 | 3504 | 4365 |
| concentrates | kg DM/LU/year | 306 | 184 | 139 | 712 |
| crude protein | % crude protein | 12.0 | 0.6 | 11.2 | 13.0 |

[1.] Managed land includes municipal proprieties (highland and transition pastures) plus farmland. [2] LU: Livestock Unit, including cows, bulls and replacement. [3] S: spring, A: autumn. [4] BW: Body Weight. [5] ADG: Average Daily Gain. [6] DM: Dry Matter. [7] The calves (male and female) for fattening were not considered in this table because any farm provided pasture.

## 3.2. Farmland Productivity and Manure Inputs

None of the effects included in the linear mixed models analyzing productivity and manure load reached statistical significance (Supplementary Table S4). For an easier presentation, we will show the data as boxplots of the non-transformed values. Median productivity values (Figure 4, left panel) were 4696 kg DM/ha for the natural meadows, 3264 kg DM/ha for the seminatural meadows, and 4159 kg DM/ha for the temporary crops, but variability was extremely high. The organic fertilization with solid manure had median values of 27,090 kg/ha for natural meadows, 30,104 kg/ha for seminatural meadows and 38,366 kg/ha for temporary crops. As for productivity, variability was very wide.

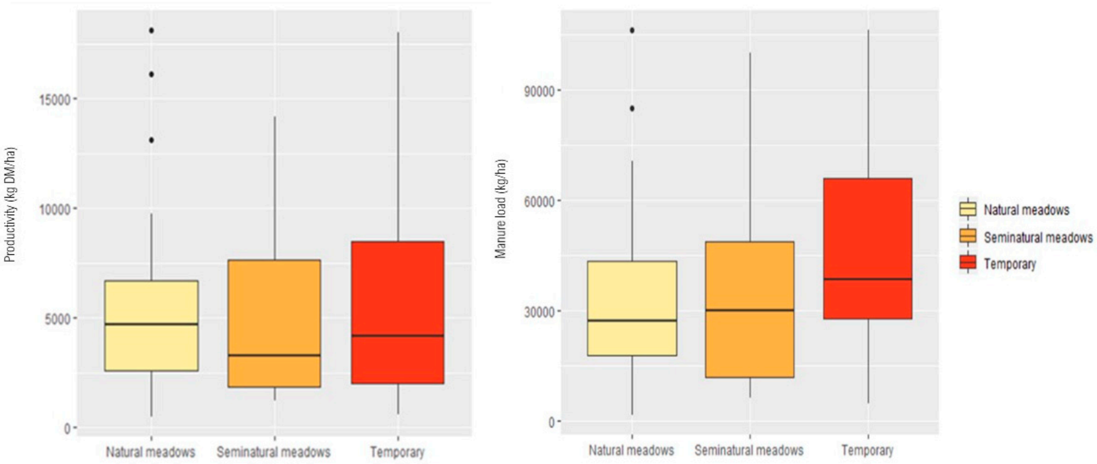


**Figure 4.** Box plots of productivity (a panel, on the left) and manure load (b panel, on the right) per type of land use.

Sixty percent of the farmers declared that they would like to change the use of part of the parcels, in all cases by shifting from natural or seminatural meadows to temporary crops in order to produce more, because they considered these parcels to be more productive and very fertile, or because their location was near the farm and easily accessible. After correcting for land use, however, productivity and manure load values did not differ between parcels candidate or not candidate to a shift in land use (Figure 5).

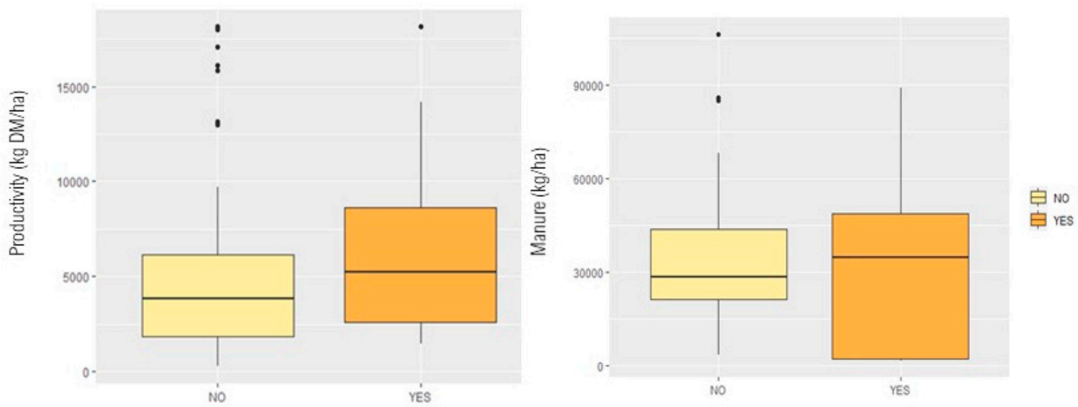


**Figure 5.** Box plot of distributions of productivity and manure loads of land parcels according to the willingness of farmers to shift or not their land use.

## 3.3. Nitrogen Balance, Environmental Impacts and Production Efficiency

The results of nitrogen balance, expressed per LU and year, are given in Table 3. Due to the low DM intakes and crude protein contents, nitrogen intake was also low (72 ± 7 kg N/LU/year). This, despite the low nitrogen retention (10 ± 1 kg N/LU/year) due to the moderate intensity of beef production, led to a modest nitrogen excretion (62 ± 6 kg N/LU/year). Concerning the environmental impacts, GWP was 13.4 ± 0.7 kg $CO_2$-eq/kg BWG, and AP averaged 189 ± 23 g $SO_2$-eq/kg BWG. The ranges were from 12.5 to 14.4 kg $CO_2$-eq/kg BWG for GWP and from 161 to 223 g $SO_2$-eq/kg BWG for AP.

**Table 3.** Values of nitrogen input–output, environmental impacts and energy efficiency.

| Variable | Mean | SD | Min | Max |
|---|---|---|---|---|
| Nitrogen balance | | | | |
| Nitrogen intake, kg N/LU [1]/year | 72 | 7 | 65 | 84 |
| Nitrogen retention, kg/LU/year | 10 | 1 | 9 | 12 |
| Nitrogen excretion, kg N/LU/year | 62 | 6 | 56 | 73 |
| Nitrogen to field, kg/LU/year | 28 | 3 | 23 | 32 |
| Environmental impacts | | | | |
| GWP [2] (kg $CO_2$-eq/kg BWG [3]) | 13.4 | 0.7 | 12.5 | 14.4 |
| AP [4] (g $SO_2$-eq/kg BWG) | 189 | 23 | 161 | 223 |
| Energy efficiency | | | | |
| ECR [5] (MJ feed/MJ beef) | 52.2 | 2.6 | 47.4 | 55.2 |
| HeECR [6](MJ feed/MJ beef) | 2.6 | 1.3 | 1.3 | 5.6 |

[1] LU: Livestock Unit. [2] GWP: Global Warming Potential. [3] BWG: Body Weight Gain. [4] AP: Acidification Potential.
[5] ECR: Gross Energy Conversion Ratio. [6] HeECR: Potentially Human Edible-Gross Energy Conversion Ratio.

The energy efficiency values (MJ feed/MJ of raw boneless beef) were low for total energy (ECR = 52.2 ± 2.6 MJ feed/MJ beef) but high for the human-edible energy (2.6 ± 1.3 MJ feed/MJ beef) (Table 3).

Figure 6 shows the contribution of each emission source to GWP and AP. For GWP, the main contributor was enteric $CH_4$ (around 70%), with manure and land management contributing less (around 20%). The contribution of off-farm inputs, essentially purchased feedstuffs, was around 10%. For AP, off-farm inputs contributed to 10–22% of emissions. Regarding AP, the main contribution was due to manure management (storage) whereas the fertilization given by the release of animal manure to pasture, the solid manure fertilization of meadows and crops and the off-farm feedstuffs gave a similar contribution.

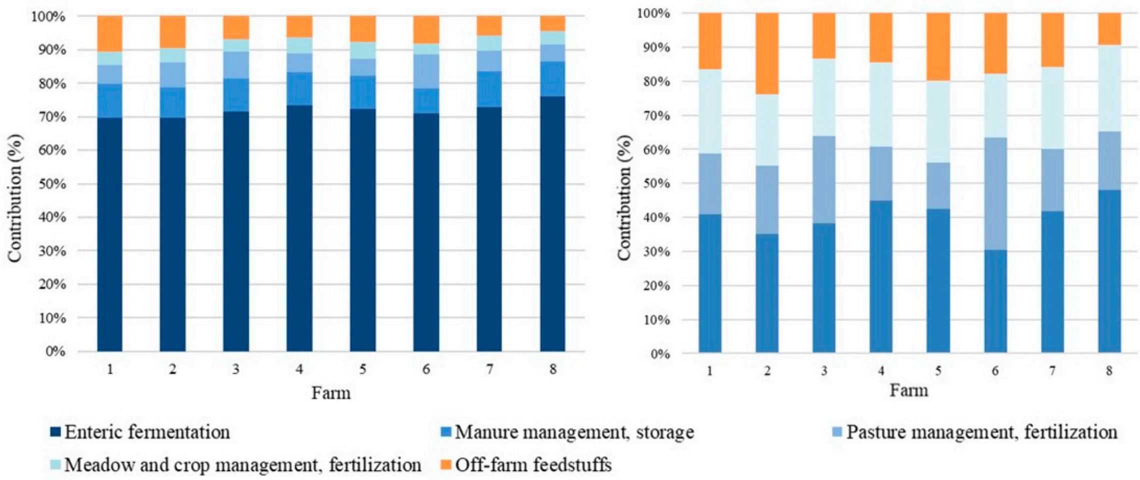


**Figure 6.** Contribution of each emission source to AP (left panel) and to GWP (right panel), for each farm. Enteric fermentation (due to microbial anaerobic fermentation in the rumen) only contributed to GWP.

## 4. Discussion

Organic beef production is typical of the Catalan Pyrenees and the number of organic farms is rapidly growing [27,41]. In this study, the farming systems implicated in such production demonstrated a strong link with the local grassland agroecosystems and, considering the specific context, good productive traits. Our results suggested also that no advantages can be automatically expected by intensifying farmland management through converting meadows to temporary crops. The LCA assessment finally complemented these findings by indicating that the impacts per LU or unit of BW are moderate, and that the low input management and the high feed self-sufficiency of these farms keep very low the contribution of off-farm stages. The conversion efficiency of diet energy was low when the total energy was considered, but high when only feeds not edible for humans were considered. We will discuss below these findings and their implications for the farms and organic beef sustainability.

### *4.1. Farms Features, Land and Herd Management*

The age of the farmers interviewed was on average lower than that observed in other studies addressing the evolution of livestock systems in marginal areas of Spain [25,59], and showed a wide variability, which reflects a generational turnover (in various cases, the farm was managed by the son, and five of the eight farmers were less than 40 years old) essential for the continuity of farming. This turnover seems to happen without remarkable changes in the traditional land use and management, that was essentially based on grazing collective pastures and on cultivating natural and seminatural meadows in the private farmland. The use of pastures is linked to the practice of summer transhumance to high elevation collective pastures, which is still widespread in the mountain areas of Europe [60] and can be essential for reducing labor and costs and for complementing the forage farm budget of traditional, extensive farming systems [61]. Interestingly, here this practice has not been simplified, as for instance has happened in other mountain areas [62] with the direct transhumance from the permanent farms to the highland pastures and the abandoning of the transition pastures, which has resulted in their loss because of natural re-afforestation [63]. Meadows in farmland are mostly natural and managed extensively with low stocking rates and little external inputs (see below). These findings suggest that the farms surveyed play an important role for the conservation of local high natural value farmland, the associated biodiversity, and the cultural landscape [64]. In this respect, it is also interesting that the average surface of land managed per farm, both because of a larger size of the farmland and of the use of collective highlands and transition pastures, was wider than that observed in other studies [65,66].

Herd sizes were also larger than those reported in other studies conducted in Spain [25,59], and the herd management was characterized by a long cow lifespan which reduced the replacement rate and by fattening performances of calves that are lower than those that can be obtained with intensive fattening practices [67,68] but are still remarkable. This implies that the calf BW marketed annually by a farm, especially having in mind that all farmers are part-time employed, may substantially contribute to their families' budget. This is remarkable also because it is obtained mostly using the local forage resources. Considering together in-house diets of fattening calves and cows, and the substantial contribution of the grass grazed at pasture, the annual feed budget of the farms included a very modest proportion of purchased concentrates, even in comparison with suckler cow–intensive calf fattening systems in other areas [33].

Within this general picture, however, we also found very high variability between farms in the size of pastures used and farmland, and consequently in herd size, which was associated with extremely high variability in the duration of the in-house period for cows and also, although less marked, for fattening calves (see Table S2). Additionally, although the use of traditional individually administered diets was still predominant for fattening calves, three farmers (Table S2) used group feeding with total mixed rations. Apparently, therefore, there is an ongoing process of modification of farming practices. We suggest that future studies, on a larger sample of farms, should address how these practices are evolving in relation to size of managed land and herd, and in general, with the structural and management conditions that it was not possible to address in this study.

*4.2. Farmland Forage Productivity and Manure Load*

We found that there were no differences in forage production and manure loads between different intensities of farmland management, respectively, natural meadows, seminatural meadows and temporary crops. This result was surprising and mostly depending on the high variability observed between parcels of the same management regime, which was not reduced by using slope, irrigation and farm as explanatory variables in the statistical analysis. In accord with Chocarro and Reiné (2008) [69], this variability most probably depended on interactions between geographical and topographical conditions (soil features, density of vegetation cover and shrubs/trees presence, aspect, accessibility, distance from the farm, etc.) and management practices (number of cuts, amount of irrigation water provided, nutrient balance and periods of manure spreading, etc.) that were not considered in this study. Similarly, the meadow parcels that the farmers would like to convert to permanent crops did not show higher productivities and manure loads than the other parcels, suggesting that they were not actually more fertile or already managed more intensively. The implication of these findings is that a change of land use from natural/seminatural meadows to temporary crops would not automatically lead to higher forage productions, as farmers believed and desired in order to reduce the off-farm feed purchase.

In absence of an improvement in the forage budget of the farms, conversion choices could result in an increase of costs and impacts (see below) due to mechanization and intensification of cultivation practices, and in a loss of incentives for the maintenance of permanent grasslands that are provided by the European CAP [66]. Alternatively, increased farmland productivity could be potentially obtained by improving the management practices of meadows. For wise decisions on either option, we argue that priority should be given to obtaining knowledge on the stationary and management factors determining the wide variability observed in parcel productivity, in order to ascertain their suitability to temporary crops and/or to rationalize present practices of meadow management and reduce yield gaps. Additionally, grassland management choices should be balanced against their potential consequences on the associated ES [62], as the natural biodiversity and conservation of specific grassland habitats, which would be lost with the conversion to temporary crops [70,71] or even with the intensification of grasslands management [61,69], which generally implies a trade-off with their natural biodiversity, as observed in the study region and other mountain areas [46,47]. The role of extensive grasslands management for ensuring both forage production and quality and conservation of biodiversity, vegetation and landscape dynamics and landscape is complex [3,72,73] and linked to the local conditions, and we stress the importance of improving knowledge on these interactions.

*4.3. Farms Impacts and Efficiency Ratios*

The nitrogen excretion values estimated per LU in this study were higher than those indicated for Spain by Šebek L. B. et al. (2014) [74], similar to those estimated in other studies regarding suckler cow–calf systems in Germany by Dämmgen et al. (2013) [75], and lower than those of integrated suckler cows–fattening bulls in other mountain areas [51]. The remarkable variability between farms depended on that of permanence at pasture, which influenced the nitrogen ingestion and excretion at the farm (grass at pasture contained a higher percentage of crude protein). In fact, the use of pastures can be a strategy not only to reduce costs and complement the forage budget of mountain farms, but also to reduce the on-farm emissions [76].

The values of GWP and AP obtained cannot be directly compared with the literature because the system boundaries did not consider other inputs like the bedding or the fuel (due to lack of information); however, these inputs are likely low in systems with a high use of pasture, and the range of impact values found here were within the variability observed in other studies on suckler cow–calf systems, e.g., de Vries et al., 2015 [33] and Berton et al., 2017 [51]. As expected, and in agreement with

Battaglini et al. (2014) [77] and Horillo et al. (2020) [78] the main contributor to GWP was enteric fermentation followed by off-farm feedstuffs and by manure management. Regarding AP, the most important emission source was manure management.

Apart from these results, which confirm that the livestock systems have moderate impacts per LU and, given the low stocking rates, also per unit of land, the most important indication of the LCA assessment was that GWP and AP emissions were predominantly related with the on-farm stages, with a share on the total emissions that, especially for GWP, was higher than that observed not only in intensive systems, but also in other extensive systems [29,36]. Even considering that the off-farm stage in this study is slightly underestimated because we could not compute bedding and fuel, this implicates that most of the resources used in the production process are obtained from the local territory, in a balance between production and mountain agroecosystems resources. The link with local resources is a feature of many mountain extensive livestock systems [79,80] but is particularly strong in the farms surveyed in this study, demonstrating an almost closed cycle at the farm level between production inputs and outputs. This self-sufficiency is important when evaluating the energy efficiency of the farms. The ECR values, which indicate the total diet energy needed to obtain a beef energy unit, were higher than those computed in other studies e.g., Wilkinson (2010) [81] or the Italian contribution to the integrated France–Italy beef production system estimated by Berton et al. (2017) [51], indicating lower efficiency; the HeECR values, which indicate the diet energy of feed potentially edible for humans needed to obtain a beef energy unit, were lower, indicating high efficiency. The results of various recent studies clearly indicate that there is a trade-off between total energy efficiency and human edible energy efficiency in ruminant feeding and that extensive ruminant systems compete less than intensive systems with the use of land and derived food suitable for humans [56,80,82,83]. The interest in the feed/food competition and the role of ruminants in the future sustainable food systems is recent but growing rapidly [84,85] and, in this respect, the very high self-sufficiency and the use of grassland-derived feed are positive features of the livestock systems examined here.

According to Ripoll-Bosch et al. (2013) [86], it was possible to state, therefore, that these livestock systems presented a great multifunctionality because they produced high-quality organic beef and, by animal grazing and extensive management practices, guaranteed a series of ES. Pasture-based LFS present a lot of synergies that allow to develop complementary activities (green and agro-tourism, education, etc.), a new market way based on consumer demands based on safety, quality and organic food products, a series of ES in terms of public goods (landscape maintenance, biodiversity, cultural heritage, etc.) [64]; evaluating the synergies is important to create an added value to the organic beef supply chain and to enhance its relationship with the land.

Farmers could reduce emissions through their work, but it was important to remember that these farms were not located in areas with high productive vocation.

## 5. Conclusions

This study has outlined a set of positive synergies between the production of organic beef and the use of mountain grassland agroecosystems. The farms surveyed here manage a remarkable surface of pastures and meadows, with extensive practices and low stocking rates, manure loads and emissions per LU. The herd productivity is moderate but, given the part-time employment of farmers and the low labor management practices, it seems to be economically sustainable and able to provide additional income for the farmers' families. An encouraging indication in this respect derives from the generational turnover which is ensuring the continuation of farming.

Our results also suggest that caution should be used in attempting to improve productivity by converting meadows to temporary crops, or by intensifying management practices of grasslands. Indeed, we found no significant differences in terms of productivity and manure loads between different intensities of farmland management (natural meadows, seminatural meadows and temporary crops), which means that a change of meadows to temporary crops, as farmers would like, would not directly lead to an increase in production. The land management choices should be therefore supported by an understanding of the environmental and management factors that actually influence productivity, and weighted against the possible consequences on the non-marketable benefits associated with the present agroecosystems, e.g., a loss of ES such as biodiversity, protection from invasive species, cultural landscape.

Regarding the environmental impacts, results show that the emissions are mainly related to on-farm stages, with respect to off-farms ones. External inputs are very low, and this farming system shows a very high self-sufficiency and ability to transform feeds non edible for humans into organic beef, a high-quality food. Overall, these findings suggest a strict and positive link between the production of organic beef and the conservation of agro-ecosystems of high natural value, with the associated ES.

Although we did not directly address the sustainability of the livestock system examined, our results can provide indirect indications and suggestions for future investigations. In a perspective of sustaining the organic beef production chain, identifying and assessing the various benefits delivered by this production could be useful to devise strategies both for the market valorization of the product and for designating sectorial policies. The organic label is a plus on the market, which could be further supported by communicating to consumers the ES associated with this specific production chain. Payments to farmers within the PAC framework could be better tailored according to the definition of the farming practices that support the agroecosystems and their services. We maintain that this is a key point for the sustainability of these farming systems and should be considered a priority in the European PAC. Finally, although we focused on organic systems, we believe that the general implications of our study could be extended also to conventional, grassland-based systems.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2071-1050/12/21/9274/s1, Table S1: Information collected during the survey about farm characteristics and management, Table S2: composition of the diet fed to suckler cows and calves (male and female) (kg DM/head/day). Regarding the calf (male and female) for fattening, a distinction has been made between farms with TMR and farms with a traditional fattening system, Table S3: equations used to compute the environmental impacts, Table S4: Coefficients of the linear mixed models analyzing log-transformed data of productivity (Kg DM/ha) and manure load (Kg/ha) of parcels with the fixed effects of land use, irrigation, slope and their interaction, the willingness to change land use the random effect of farm.

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